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A generalized discussion of mathematical simulation used on the Great Lakes is presented for the layman. Illustrations of model utilization are presented and the complexities of ecosystem simulation are noted.

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The Computerized Ecosystem

The widely misunderstood tool of mathematical modeling helps ecologists answer many questions about the lakes

by Wayland R. Swain

Several years ago, a group of scientists associated with the Environmental Protection Agency prepared a mathematical model of Lake Erie. The model was designed to predict the extent of anoxia (oxygen deprivation) in the lake as a result of increased nutrient loads from sewage treatment plants, factories, the atmosphere, and farms. For a number of years, scientists had been concerned with the accelerated rate of eutrophication of Lake Erie brought about by the discharge of the wastes of human activity. Lake Erie had become so highly productive of undesirable nuisance algae and so depleted of oxygen in its lower layers that the popular press was moved to report that the lake was dying.

The modelers considered many agents and processes in their mathematical simulation of how the lake ecosystem worked. Through a complex series of equations, they were able to mimic in a computer the seasonal cycle of the lake.

Use of the model simulating Lake Erie's aging process suggested that the size of the area of anoxia appeared to be related directly to the extent of nutrient loading into the lake. But in 1975 the anoxic area was found to be markedly smaller than predicted by the model. To all appearances, the efforts of ecologists and environmentalists were having a major effect, even though the model suggested that the lake's improvement was so rapid and drastic as to be unbelievable. The press now began to herald the "rebirth" of Lake Erie, and some scientists grudgingly admitted that the lake apparently was improving, despite what the model had predicted.

As public awareness heightened, pressure for complete answers to the question of the vitality of Lake Erie grew. When Great Lakes modelers examined 1975 inputs, they discovered that nutrient loadings were similar to those of previous years and that, with a single exception, all important variables had remained significantly unchanged.

The single altered variable was temperature. Spring arrived much earlier in 1975 than it had in previous years and without the fresh winds that usually accompany its coming. As a result of the early rapid warming and minimal mixing, only a small portion of the lake's water made up the warmer surface layer that floats in the cold, deep water. The greatly increased fraction of deep water was freshly charged with oxygen after the recent spring overturn, in which the entire lake was mixed. Consequently, in 1975 a vastly increased amount of oxygen was available to satisfy the needs of respiring algae, decomposing plant matter, and the sediment. The excess of oxygen in deep waters gave an impression of a vast improvement in the amount of available oxygen in the entire lake, which in turn suggested that the lake had improved considerably over previous years. Ultimate confirmation of the interpretation of the 1975 "recovery" of Lake Erie as a result of an anomaly in climate was achieved in 1976 and 1977, when spring came at its normal time, more water was warmed, and Lake Erie returned to its usual state of widespread anoxia.

The cause of this apparent, short-lived improvement in Lake Erie's condition would probably still not be understood if the tool of mathematical modeling of environmental simulation had not been available. Yet, despite its merits, no other scientific technique may be as widely misunderstood by both scientist and layperson as is this one.

Much of the problem seems to lie in the absence of a common language about modeling. Since the language of mathematical simulation is unknown to the general public, to many managers, and even to a good proportion of the scientific community, the subject seems to generate feelings of apprehension and distrust.

The language that we have shared since childhood suggests that a model is a physical reality, a representation (usually in miniature) of an object. Often, this representation shows the construction, or is a copy, of the original. But while most of us can understand that meaning of "model," very few of us have been exposed to the concept of numerical simulation and the function it is intended to perform.

Reduced to its essence, a mathematical model is more than a simple organization of coefficients, equations, and computer programs—although those are the ways in which the measurements in the model are expressed and calculated. A model is a dynamic conceptual framework, a continually growing numerical idea, and if you will, a vision of the future. The environmental modeler conceptualizes a mathematical scheme in which he is able to measure existing states of the environment, to evaluate how those states are interrelated in the ecosystem, and to look forward in time and envision the state of the environment for future generations.

Just as human perception grows with the acquisition of increasingly more information, ecological modeling is a dynamic process. A scientist defines quantities of substances, events, and creatures in numerical shorthand (for ease of understanding). The modeler working with the Great Lakes system must develop a wide understanding of many disciplines in order to conceptualize the major processes at work. Because these processes are so tightly interwoven with living systems

(and because of the enormity of space and time scales), simple empirical and intuitive approaches are not adequate. The analytic approach must be iterative, growing, and dynamic if it is to include large amounts of new information.

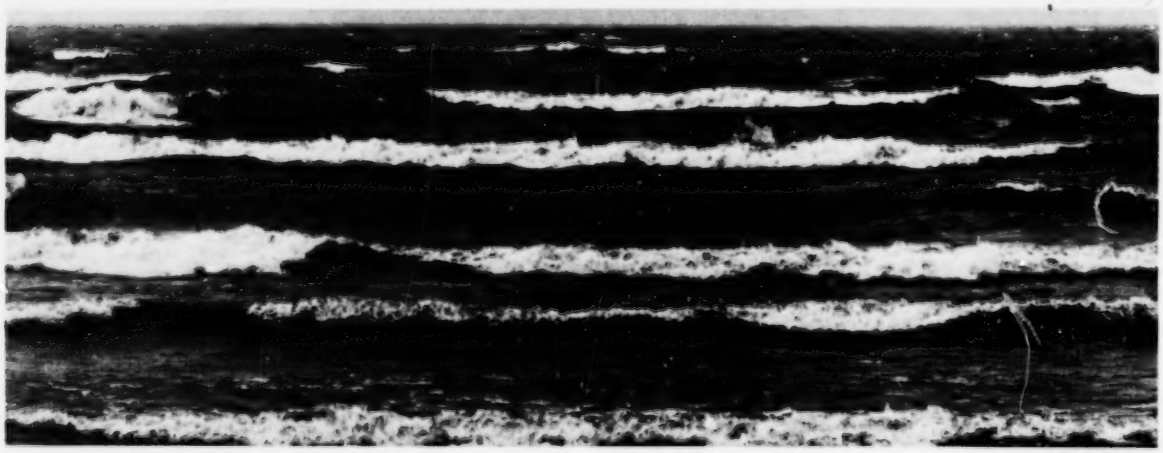
A typical modeling program might begin in the Great Lakes with the simplest of all approaches—the mass balance model. "Everything has to go somewhere," say the laws of conservation of energy and matter. The mass balance model is meant to define the manner in which a given amount of a substance goes from one place to another or from one physical or chemical state to another. This model can be used to analyze the change in concentration of a Great Lakes pollutant over time by considering (1) the amount of the pollutant added to the system from all sources; (2) the residence time of the water in the system; (3) the length of time the pollutant remains in the water; (4) the internal loss rate of the pollutant to the sediment and to organisms; and (5) the rate at which the pollutant is swept out of the lakes. The lakes may be regarded as a single, continuously stirred system, or they may be broken up into subdivisions either by area or by depth. Even the simplest models quickly develop an insatiable appetite for data, and additional information can expand the horizons and refinement of the model. As the conceptual system of the model becomes more complicated, the amount of data and number of solutions increase rapidly. In the larger environmental models, which relate many complex ecological events, a computer often must solve simultaneous algebraic equations for several hundred unknown entities.

Before a model can be used for prediction, two final steps—calibration and verification—must be performed. Calibration involves comparing measured data with calculated model results, then making adjustments in the model until the measured and calculated data match. Scientists then verify the model by matching calculated values with a set of independent data that were not used to develop the model. Once calibrated and verified, the model may be used to simulate the impacts of various alterations in the ecosystem and to anticipate outcomes.

In the future, Great Lakes modeling and simulation efforts can be expected to provide answers to problems that cannot be effectively attacked in a more traditional way. One of these areas of current scientific concern is that of such toxic and carcinogenic materials as pesticides, polychlorinated biphenyls, plasticizing compounds, and polynuclear hydrocarbons.

Among the questions that mathematical modeling should be able to answer are, What are the origins of these materials? How do they affect the ecosystem? What is their fate? How do they affect the food chain? If banned immediately, how long will they persist?

If one takes into account the many effects of stratification and other aspects of the seasonal cycle, retention time for water and pollutants in these huge inland seas varies from three (for Lake Erie) to five centuries (for Lake Superior). Thus, management of toxins and pollutants concerns the distant future as much as it does tomorrow. The answers to these and other questions about the lakes, when provided by mathematical models of the environment, can supply managers with the information necessary to adopt effective control policies. □



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